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Susceptibility measurements near the ^{3}He liquid–gas critical point

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Abstract

A new electrostriction technique and the conventional pressure–density method were used to determine the susceptibility near the liquid–gas critical point of ^{3}He. Measurements were made along the critical isochore over the reduced temperature range of $3\times10^{-5} < T/T_c - 1 < 7\times10^{-3}$. Preliminary results were compared with previous experiments and were fit to $\chi_T^* = \Gamma_0^+ t^{-\gamma}(1 + \Gamma_1^+ t^{\Delta})$. Best fit parameters for the asymptotic amplitude Γ_0^+ and the first correction-to-scaling amplitude Γ_1^+ are presented.

Keywords: Critical phenomena; ^{3}He normal liquid; Susceptibility

1. Introduction

A space flight experiment, called microgravity scaling theory experiment (MISTE), is being developed to test scaling predictions near the liquid–gas critical point of ^{3}He. One of the objectives of this experiment is to accurately measure the susceptibility along the critical isochore in the single-phase region. The susceptibility is defined as $\chi_T \equiv \rho(\partial\rho/\partial P)_T$ where ρ is the fluid density and P is the pressure. The conventional technique for determining the susceptibility uses P, ρ measurements along an isotherm [1]. An accuracy of 1% in χ_T along the critical isochore ($\rho = \rho_c$) at $t \equiv T/T_c - 1 = 1\times10^{-6}$ would require a pressure sensor with a resolution of $\delta P/P \approx 10^{-10}$. This resolution cannot easily be obtained using conventional pressure sensors.

In 1962, Hakim and Higham [2] experimentally determined that a pressure increase in a dielectric fluid could be induced by an electric field gradient. This electrostriction effect was recently observed by Zimmerli et al. [3] in a microgravity experiment near the critical point of SF_6. The present paper discusses our recent application of this electrostriction effect to measure the susceptibility near the ^{3}He liquid–gas critical point ($T_c = 3.31$ K).

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2. Experiment and results

These ground-based measurements were performed using a parallel-plate capacitor having a 0.84 cm diameter and a 0.0061 cm gap that was immersed in the middle of a ^{3}He sample cell (0.05 cm high by 11.2 cm in diameter) [4]. By applying a constant DC bias voltage across the capacitor, a uniform electric field, E, was generated in the capacitor gap. In the limit of $E \to 0$, the susceptibility of the fluid within the gap is given by [3]

$$\chi_T = \frac{\rho_c^2}{P_c}\chi_T^* = \frac{6\rho\delta\rho}{\varepsilon_0(\varepsilon - 1)(\varepsilon + 2)E^2}. \quad (1)$$

Here ε_0 is the permittivity of free space and ε is the dielectric constant of the fluid which is related to fluid density via the Clausius–Mossotti equation. The susceptibility can thus be determined by measuring the density change upon an application of a known electric field. In our experiment, a series of $\delta\rho$ were measured against various E, then the ratio of $\delta\rho/E^2$ was extrapolated to $E = 0$. This extrapolated ratio was used in the calculation of χ_T^* using Eq. (1).

In Fig. 1, the susceptibility χ_T^* for two electrostriction runs and two P, ρ isotherm measurements in the present cell are compared to previous studies [1,5]. For $t < 1.2\times10^{-4}$, the experimental data exhibit a strong gravity effect. For $t > 2\times10^{-3}$, χ_T^* is small and large E values are

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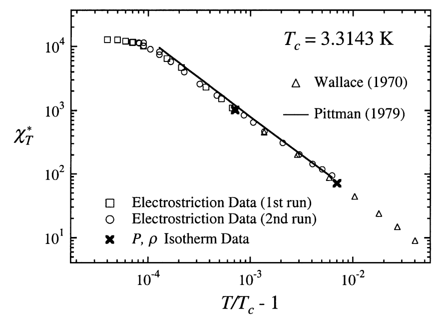

Fig. 1. Measured susceptibility versus reduced temperature along the critical isochore. The sample cell temperature was regulated better than 10 nK.

required. The small signal-to-noise ratio and the correction in the measured capacitance change due to large E made these data less accurate.

The susceptibility along the critical isochore in the single-phase region is expected to behave as

$$\chi_T^* = \Gamma_0^+ t^{-\gamma}(1 + \Gamma_1^+ t^{\Delta} + \cdots). \quad (2)$$

The measured susceptibility data (open circles) in Fig. 1 were fit over the temperature range of $1.3\times10^{-4} < t < 2\times10^{-3}$ to Eq. (2). In the fit, the critical exponents were fixed to their theoretical values $\gamma = 1.239$ and $\Delta = 0.5$. The critical temperature, T_c, and the fluid-dependent critical amplitudes Γ_0^+ and Γ_1^+ were adjusted. The deviations from the fit were random and less than 5%. The best fit values were $T_c = 3.31429$ K $\pm$ 40 μK, $\Gamma_0^+ = 0.11 \pm 0.015$, and $\Gamma_1^+ = 7^{+5}_{-4}$. Uncertainties given for the parameters were determined from confidence contours that correspond to a 2σ (95.4%) confidence limit for each parameter [6]. These errors represent a more realistic estimation of errors than the diagonal elements of the error matrix. These rather large estimated errors are mainly due to the current limited reduced temperature range and few data points. A similar confidence limit error analysis performed on the data from a previous study [5], (see solid line in Fig. 1) showed that our current estimation of fitting parameters are consistent with their values within estimated errors.

There is a need to perform measurements closer to the transition to unambiguously determine the values of fitting parameters. This is one of the objectives of the proposed microgravity flight experiment. Future ground-based experiments are planned that will combine electrostriction measurements close to the transition with P, ρ measurements farther away. This wider range of data should permit a more accurate determination of Γ_0^+ and Γ_1^+.

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